No energy compensation at the meal following exercise in dietary restrained and unrestrained women

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The objective of this investigation was to compare the acute effects of exercise and diet manipulations on energy intake, between dietary restrained and unrestrained females. Comparisons of two studies using an identical 2 × 2 repeated-measures design (level of activity (rest or exercise) and lunch type (high-fat or low-fat)) including thirteen dietary unrestrained and twelve restrained females were performed. Energy expenditure during the rest session was estimated and the energy cost of exercise was measured by indirect calorimetry. Relative energy intake was calculated by subtracting the energy expenditure of the exercise session from the energy intake of the test meal. Post-meal hedonic ratings were completed after lunch. Energy intake and relative energy intake increased during high-fat conditions compared with the low-fat, independently of exercise ($P < 0{\cdot}001$). There was a positive relationship between dietary restraint scores and energy intake or relative energy intake in the rest conditions only (r 0·54, $P < 0{\cdot}01$). The decrease of relative energy intake between the rest and exercise conditions was higher in restrained than in unrestrained eaters ($P < 0{\cdot}01$). These results confirm that a high-fat diet reversed the energy deficit due to exercise. There was no energy compensation in response to an acute bout of exercise during the following meal. In restrained eaters, exercise was more effective in creating an energy deficit than in unrestrained eaters. Exercise may help restrained eaters to maintain control over appetite.

Physical activity: Energy intake: Dietary restraint

Restrained eating has been defined as the tendency to restrict food intake consciously in order to prevent weight gain or to promote weight loss (Herman & Mack, 1975; Herman & Polivy, 1975). Dieting, however, implies a restriction of food intake entirely undertaken in order to promote weight loss. Restrained eaters, lean or obese, stop eating not in response to satiety but because they have reached a cognitively-set limit. An association between dietary restraint and reduced energy intake has often been reported in adults (van Strien *et al*. 1986; Wardle & Beales, 1987; Laessle *et al*. 1989; Tuschl *et al*. 1990; Klesges *et al*. 1992; French *et al*. 1994; de Castro, 1995; Green & Blundell, 1996), adolescents (Wardle *et al*. 1992) and children (Hill & Robinson, 1991). However, a central hypothesis of the dietary restraint theory is that the intent to diet may be disrupted by certain events such as preloads of food, alcohol and dysphoric emotions (for review see Ruderman, 1986). This phenomenon is related to the disinhibition of cognitive control of eating behaviour and it leads to episodes of overeating. Weight fluctuations may be experienced as a result of these alternate periods of restrained and uncontrolled eating (Hill *et al*. 1995), and therefore make the attempt to control body weight unsuccessful.

Physical activity can be considered as a method of creating an energy deficit in order to control body weight, providing that there is no or incomplete energy compensation following exercise. When assessing the possibility of energy compensation in response to exercise, the potential theoretical differences between restrained and unrestrained eaters have been previously highlighted as an important consideration (Hill *et al*. 1995). According to this model, lean unrestrained individuals (those who do not diet and do not cognitively control food intake) would respond to increased physical activity by increasing their food intake. Restrained individuals who are currently dieting might either choose to maintain constant food intake or to decrease it in order to obtain or accelerate weight loss. If the restrained individuals are not currently dieting, it would be unlikely to observe changes of energy intake in response to increased physical activity unless subjects are responsive to cues of hunger and satiety.

In order to test the hypotheses described in this model, the aim of this present paper was to compare the short-term

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effects of exercise and diet composition on appetite control between dietary restrained and unrestrained females. The data needed to perform these analyses were available from two separate studies with identical designs, conducted in the same laboratory (King *et al*. 1996; Lluch *et al*. 1998). In the present paper, the effects of exercise on energy intake and food hedonic ratings are addressed by re-analysis of these previously collected data. In the rest conditions (which should be comparable to free-living and 'normal life' situations), energy intake was expected to be lower in restrained than in unrestrained females. After exercise, two hypotheses are suggested. Either reduced energy intake could be accentuated in restrained eaters or alternatively, exercise could relax the control of food intake in these subjects, leading to increased energy intake. Changes in the perception of food hedonics after exercise could possibly have an additional effect.

Methods

The data used in this study were available from two previous investigations carried out in unrestrained and restrained females (King *et al*. 1996; Lluch *et al*. 1998). Details regarding the methods have been previously described in the corresponding publications.

Subjects

Subjects were recruited from the student population of Leeds University, Leeds, UK, to complete the study. Data were collected from twenty-five normal-weight, regularly exercising females, defined as unrestrained or restrained eaters by the Three Factor Eating Questionnaire (Stunkard & Messick, 1985). Restrained subjects scored strictly above 10 on the restraint scale. All subjects from both groups were regular exercisers (at least three sessions of 30 min of moderate to vigorous exercise per week), non-smokers and were not taking any medication. Heights and weights were measured at the beginning of the study. The experimental protocol was approved by the Psychology Department Ethical Committee at Leeds University. Subjects gave written consent and were paid for participation.

Design and procedure

The study was designed to assess the effects of a bout of high-intensity exercise followed by a free-selection lunch (varying in macronutrient composition) on energy intake and food hedonic ratings. A 2×2 repeated-measures design was used, with subjects acting as their own control. The level of activity (rest or exercise) and the lunch type (low-fat or high-fat) were the repeated factors. Individuals were assigned to each of the conditions, in a counterbalanced order, with 1 week separating each experimental day. Subjects were asked to attend the Human Appetite Research Unit in the morning of each experimental day to be provided with a standard breakfast. Quantities eaten at the first occasion were served at the three following ones, during which subjects were asked to eat all the foods provided. Subjects returned 2 h 45 min after the beginning of the breakfast to undergo one of the four following treatments: (1) Rest–low fat (Rest–LF). Subjects remained seated for approximately 50 min in an individual room and were allowed to read and/or write, after which they were provided with a low-fat test lunch (mean food quotient $>0{\cdot}85$); (2) Rest–high fat (Rest–HF). Subjects remained seated for approximately 50 min in an individual room and were allowed to read and/or write, after which they were provided with a high-fat test lunch (mean food quotient $<0{\cdot}85$); (3) Exercise–low fat (Ex–LF). Subjects cycled for 50 min at 70 % of their V_{O_2max}, after which they were provided with a low-fat test lunch (mean food quotient $>0{\cdot}85$); (4) Exercise–high fat (Ex–HF). Subjects cycled for 50 min at 70 % of their V_{O_2max}, after which they were provided with a high-fat test lunch (mean food quotient $<0{\cdot}85$).

Subjects were instructed to refrain from heavy exercise and from consuming alcohol 1 d prior to each experimental day and to keep habits and activities as constant as possible during the course of the study.

Physical activity

During the exercise sessions, indirect calorimetry was used to collect expired air samples every 10 min in order to calculate energy expenditure and to confirm that subjects were working at the required exercise intensity (70 % V_{O_2max}). Two indirect calorimetry techniques were used to measure the energy cost of exercise. A Douglas bag system and an online (Vmax 29, SensorMedics Corporation, Yorba Linda, CA, USA) system were used for the unrestrained and restrained subjects respectively. A validation study had been previously carried out in five healthy males on an ergometer at work rates ranging between 40 and 160 W. Correlations for the minute ventilation, the CO_2 output, and the O_2 uptake were 0·998, 0·997 and 0·993 respectively (Storer *et al*. 1995). On the experimental days, each subject was asked to refrain from prescribed exercise but was allowed to continue with habitual activities (e.g. walking to and from work and climbing stairs). Resting energy expenditure was estimated for each subject, using the following equation: REE (kJ) = 4·19 kJ/kg body weight per h (Ainsworth *et al*. 1993).

Lunch test meal

After the end of the exercise or rest sessions, subjects were asked to stay in an individual room within the Appetite Research Unit where their lunch was served *ad libitum*. Each test meal consisted of a choice of seven foods. For the low-fat lunch, sandwiches (cheese or tuna), coleslaw, breadsticks, pizza, fruit yoghurt, swiss roll and jaffa cakes were offered. The high-fat lunch consisted of a choice of sandwiches (cheese or tuna), coleslaw, crisps, vegetarian quiche, fruit fool, Viennese whirls and chocolate wafer biscuits. The list of all the foods, their energy and nutritional contents, food quotient and served portions have been previously detailed (Lluch *et al*. 1998). Subjects were informed that they could eat as much or as little as they wanted within a 30 min period and could select any of the food items. Subjects were not allowed to consume any foods in between breakfast and lunch but were allowed to have one drink (coffee or tea without milk and sugar, or water).

Energy and macronutrient intake

Energy and macronutrient intakes were calculated by weighing the food before and after consumption (to the nearest 0·1 g) and using manufacturer's values and a computerised version of food tables (Compeat 4.0, Nutrition Systems, London, UK). The factors used for conversion of nutrients into energy values (kJ) were 16·7, 37·7 and 15·7 for protein, fat and carbohydrate respectively. In order to investigate the energy compensation after exercise, it is important to examine the effects of exercise with respect to absolute (energy intake during the test meal) and relative energy intake (energy intake accounting for energy expenditure) (King *et al*. 1997). Therefore, the relative energy intake was calculated for lunch by subtracting the measured energy expenditure during the exercise (and estimated during the rest) session from the energy intake during the test meal (lunch).

Post-meal food hedonic ratings

After lunch, subjects were asked to complete post-meal ratings on 100 mm visual analogue scales, including palatability, tastiness, pleasantness. Questions were as follows: 'How palatable/tasty/pleasant was this meal?' with 'not at all' and 'extremely' at both extremities of the lines.

Statistical analyses

Data were analysed using SPSS (Windows Version 6.1; Chicago, IL, USA). Repeated-measures two-way ANOVA was used to analyse nutritional data and post-meal hedonic ratings with 'level of activity' (rest or exercise) and 'lunch type' (low- or high-fat) as the within-subject factors and 'group' (restrained or unrestrained eaters) as the between-subject factor. Post-hoc *t* tests were used to analyse differences between pairs of means. Pearson correlation analysis was performed to assess the association between nutritional data and scores of dietary restraint or food hedonic ratings, for each condition. All tests were conducted at the 5 % probability level.

Results

Subjects

Descriptive characteristics of the subjects are presented in Table 1. Ten out of the twelve dietary restrained females were not currently dieting. Seven dietary restrained subjects were more likely to use both exercise and dietary restraint to control their body shape or weight, two exercise only and three dietary restraint only. There were no significant differences between the two groups of restrained and unrestrained females for age, BMI and body fat. As expected, restraint scores were significantly higher in restrained than in unrestrained eaters (t 8·0, $P < 0·001$). For each group, mean energy cost of exercise, exercise intensity and RQ did not differ significantly between the two exercise sessions (King *et al*. 1996; Lluch *et al*. 1998). However, maximal O_2 consumption (V_{O_2max}) and average energy cost of the two exercise sessions were significantly lower in unrestrained than in restrained females (t 2·6, $P < 0·05$, t 3·5, $P < 0·01$ respectively). For this reason, although results of energy intake will be presented, the interest will be focused on analyses of relative energy intake which take into account the energy expended.

Energy and macronutrient intake

Energy and macronutrient intake during each of the four test lunches are shown in Table 2. There was a main effect of lunch type on energy intake (F[1, 23] 111·2, $P < 0·001$), with energy intake increased in both high-fat conditions compared with the low-fat (Fig. 1(a)). There was a level of activity × group interaction on energy intake, but this failed to reach the level of significance (F[1, 23] 3·2, $P = 0·08$): unrestrained subjects increased their energy intakes after exercise, whereas in restrained eaters energy intakes tended to decrease (Fig. 2(a)). Post-hoc tests indicated that restrained subjects ate significantly more than unrestrained eaters in the rest condition (t 2·6, $P < 0·05$) but not in the exercise condition. This difference was confirmed by a significant positive relationship between restraint scores and energy intake (average of both low-fat and high-fat conditions) in the rest (r 0·54, $P < 0·01$) but not in the exercise conditions (r 0·09, NS). When the exercise-induced energy expended was controlled for, there was a significant effect of lunch type (F[1, 23] 112·7, $P < 0·001$) (Fig. 1(b)), exercise (F[1, 23] 100·7, $P < 0·001$) and a level of activity × group interaction (F[1, 23] 8·6, $P < 0·01$) on relative energy intake: exercise decreased relative energy intake when compared to rest and this difference was higher in restrained than in unrestrained subjects (Fig. 2(b)).

There was a significant effect of lunch type on weight of food eaten (F[1, 23] 6·8, $P < 0·05$), with more food eaten during the low-fat than the high-fat conditions. A group × lunch type interaction on weight of food eaten failed to reach significance (F[1, 23] 3·2, $P = 0·09$): unrestrained

Table 1. Descriptive characteristics of the subjects
(Mean values and standard deviations)

		Age (years)		BMI (kg/m^2)		Body fat (%)		Restraint score*		V_{O_2max} (ml/kg per min)		Energy cost of exercise (kJ)	
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Unrestrained eaters	13	22·6	2·3	21·9	1·6	24·7	3·0	4·4	3·0	37·0	3·3	1455	213
Restrained eaters	12	21·7	2·2	22·6	1·9	25·6	2·2	13·3	2·5	41·0	4·4	1772	242

* Measured using the Three Factor Eating Questionnaire (Stunkard & Messick, 1985); restrained subjects scored >10 on the restraint scale.

Table 2. Energy intake (EI), relative EI and nutrient intakes (lunch) on each of the four experimental days, in thirteen unrestrained (U) and twelve restrained (R) eaters*

(Mean values and standard deviations)

	Rest–LF				Rest–HF				Ex–LF				Ex–HF			
	U		R		U		R		U		R		U		R	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Energy intake (kJ)	2725	548	3231	548	4477	782	5121	986	2993	506	2934	585	4878	995	5171	1141
Lunch relative EI (kJ)†	2525	539	3018	539	4276	773	4912	982	1534	451	1154	493	3423	1041	3407	995
Weight of food eaten (g)	356	81	478	137	287	68	442	92	427	196	456	144	309	79	456	110
Protein intake (% of energy)	18·9	2·3	18·3	2·9	9·1	1·5	9·1	1·6	18·6	3·1	18·9	2·3	9·1	1·9	9·2	2·3
Fat intake (% of energy)	20·7	3·9	25·0	2·2	65·2	4·8	65·2	7·0	20·5	3·4	25·0	1·8	65·8	5·4	64·7	5·9
Carbohydrate intake (% of energy)	60·5	4·8	56·7	4·7	24·7	2·9	25·7	6·1	60·9	5·2	56·1	3·5	24·3	2·7	26·1	4·8

Rest–LF, rest–low fat; Rest–HF, rest–high fat; Ex–LF, exercise–low fat; Ex–Hf, exercise–high fat.
* Restraint scores were calculated using the Three Factor Eating Questionnaire (Stunkard & Messick, 1985); restrained subjects scored >10 on the restraint scale.
† Relative energy intake = energy intake during the test meal – energy expenditure (measured during exercise session and estimated during rest session).

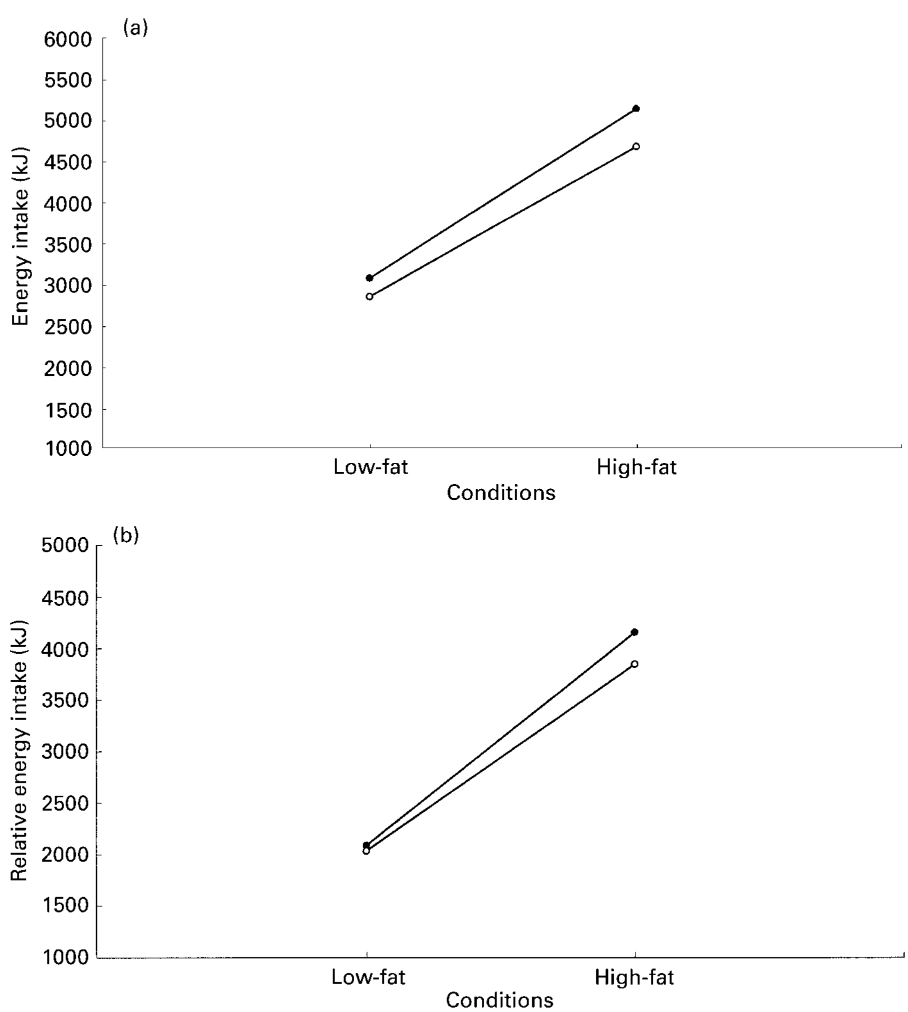

Fig. 1. Effect of lunch type on (a) energy intake and (b) relative energy intake (average of rest and exercise conditions) in twelve restrained (●) and thirteen unrestrained (○) eaters. Restraint scores were calculated using the Three Factor Eating Questionnaire (Stunkard & Messick, 1985); restrained eaters scored >10 on the restraint scale. For details of low-fat and high-fat conditions see pp. 220–221. Relative energy intake = energy intake during the test meal – energy expenditure (measured during exercise session and estimated during rest session).

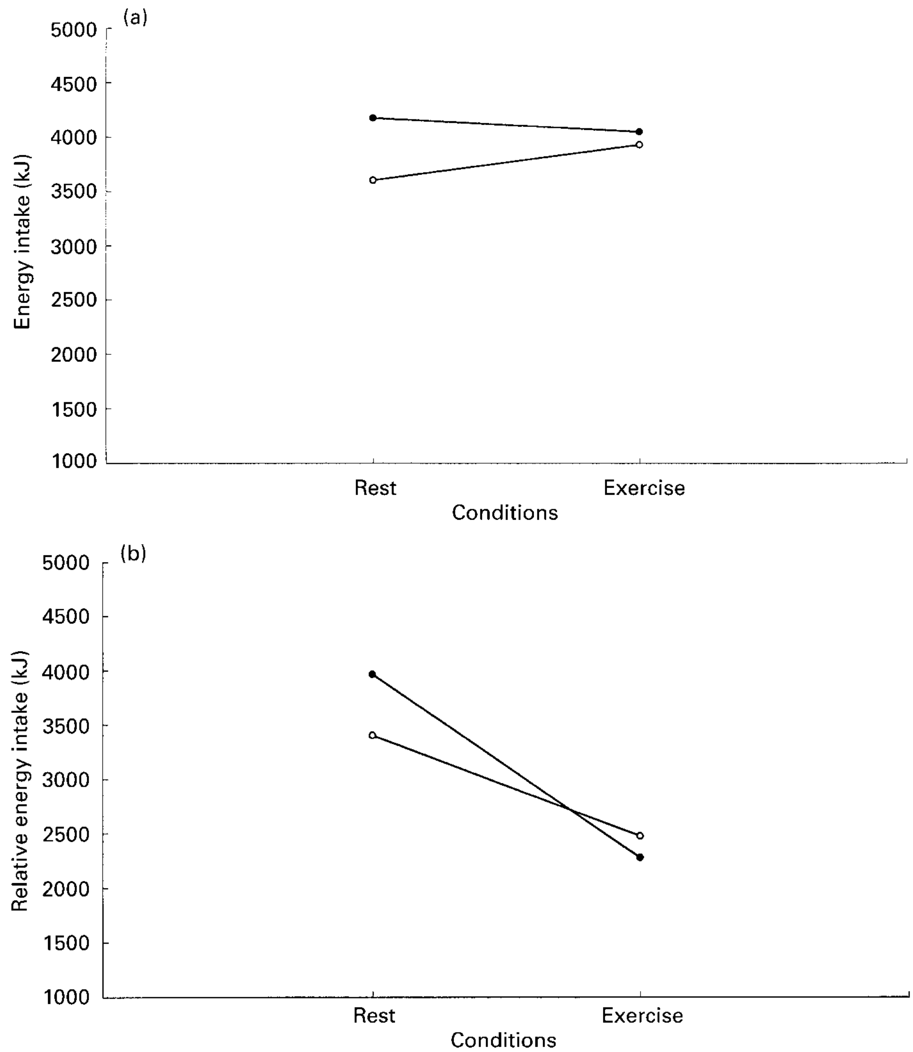

Fig. 2. Effect of exercise on (a) energy intake and (b) relative energy intake (average of low-fat and high-fat conditions) in twelve restrained (●) and thirteen unrestrained (○) eaters. Restraint scores were calculated using the Three Factor Eating Questionnaire (Stunkard & Messick, 1985); restrained eaters scored >10 on the restraint scale. For details of low-fat and high-fat conditions see pp. 220–221. Relative energy intake = energy intake during the test meal – energy expenditure (measured during exercise session and estimated during rest session).

subjects ate less (g) during the high-fat conditions, whereas restrained subjects tended to eat similar amounts regardless of the condition. As expected, there was a significant effect of lunch type on fat ($F[1, 23]$ 963·2, $P < 0·001$) and carbohydrate ($F[1, 23]$ 903·5, $P < 0·001$) intake when expressed as a percentage of energy intake.

Post-lunch food hedonic ratings

Post-lunch food hedonic ratings are shown in Table 3. Exercise significantly increased ratings of pleasantness, tastiness and palatability of the foods served at lunch ($F[1, 23]$ 19·6, $P < 0·001$; $F[1, 23]$ 11·5, $P < 0·01$; $F[1, 23]$

Table 3. Post-lunch food hedonic ratings (mm) on each of the four experimental days in thirteen unrestrained (U) and twelve restrained (R) eaters*
(Mean values and standard deviations)

	Rest–LF				Rest–HF				Ex–LF				Ex–HF			
	U		R		U		R		U		R		U		R	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Palatability (mm)	73·3	22·4	70·1	16·2	71·9	16·0	83·7	15·3	77·3	15·1	76·1	13·1	78·5	15·6	84·8	15·4
Tastiness (mm)	73·8	15·5	69·5	18·1	70·8	17·6	84·1	15·2	78·5	14·1	80·1	11·0	76·4	16·0	85·1	16·0
Pleasantness (mm)	78·6	15·7	70·9	12·9	70·8	15·9	84·9	14·6	79·9	12·5	82·5	11·1	81·2	14·6	88·2	13·3

Rest–LF, rest–low fat; Rest–HF, rest–high fat; Ex–LF, exercise–low fat; Ex–HF, exercise–high fat.
* Restraint scores were calculated using the Three Factor Eating Questionnaire (Stunkard & Messick, 1985); restrained subjects scored >10 on the restraint scale.

8·9, $P < 0.01$ respectively). When correlation analyses controlling for the level of dietary restraint were performed, there was no relationship between these food hedonic ratings and energy intake or relative energy intake, in any of the four conditions. For pleasantness ratings, lunch type × group ($F[1, 23]$ 5·6, $P < 0.05$) and lunch type × group × level of activity ($F[1, 23]$ 4·1, $P = 0.05$) interactions were found. Post-hoc analyses showed that exercise enhanced the pleasantness of foods in the high-fat and low-fat conditions in unrestrained and restrained subjects respectively (t 2·6, d.f. 12, $P < 0.05$; t 2·7, d.f. 11, $P < 0.05$ respectively). In the rest–high fat condition, pleasantness ratings were significantly higher in restrained subjects than in unrestrained (t 2·3, $P < 0.05$).

Discussion

The absence of a compensation in energy intake in response to exercise in the present study is now well documented (for review see King, 1999), but is not in accordance with the predictions of Hill *et al.* (1995) that unrestrained eaters should increase their food intake. However, as previously suggested (Lluch *et al.* 1998), it is possible that energy intake was not measured for long enough and compensation could have taken place later. Although exercise failed to have any effect on energy intake in the two separate studies involving unrestrained and restrained females, comparisons between the two groups revealed a very interesting relationship between dietary restraint and energy intake. There was a positive correlation between dietary restraint and energy intake following a period of rest, but not after a bout of exercise. This relationship was independent of the nutrient manipulation (lunch type). The boundary model for the regulation of eating, in which the control of food intake is not between physiological but cognitive boundaries, has been proposed to explain that restrained eaters ate more after a high-energy preload than after a small preload or no preload (Herman & Polivy, 1984). This phenomenon is known as 'counter-regulation' and has been linked to the concept of disinhibition: when the self-control of restrained eaters is disrupted, the loss of control leads to overeating and results in an increase of energy intake. Disrupting events, or disinhibitors, described in the literature include certain cognitions, alcohol and strong emotional states (Ruderman, 1986). In the present sample of restrained eaters, during the rest days, instead of reinforcing their level of dietary restraint (to maintain a control of their energy balance), it appeared that these females relaxed their control of food intake. Therefore, the rest condition (in which subjects were not allowed to exercise) could be considered as a disrupting event leading to the disinhibition of eating behaviour. Indeed, the role of physical activity in the control of body weight of the restrained subjects was confirmed from the debriefing questionnaire. Seven of the twelve subjects were more likely to use both exercise and dietary restraint to control their body shape or weight, two only exercise and three dietary restraint.

Another possible explanation of the positive correlation between dietary restraint and energy intake following a period of rest is that during the rest condition, subjects remained seated for 50 min in an individual room before being provided with their test lunch. This period gave them more opportunity to become preoccupied with thoughts about food. Previous studies (Rogers & Hill, 1989; Jansen & van den Hout, 1991; Federoff *et al.* 1997) have shown that pre-exposure to food cues originating from external sources (i.e. visual, olfactory or cognitive) has a significant impact on subsequent consumption, particularly for restrained eaters.

The present study also confirmed the phenomenon of 'passive overconsumption' (Blundell *et al.* 1995), that is, an increase in energy intake (kJ) in the high-fat lunches despite a lower weight of food consumed. However, this phenomenon was not observed in the restrained subjects who ate a similar amount of food (g), regardless of the condition (Lluch *et al.* 1998). This difference between the two groups supports the beliefs that restrained eaters stop eating not in response to satiety but because they have reached a cognitively-set limit which could be partly determined by the amount of food eaten.

In the present study, there were differences between restrained and unrestrained subjects in food hedonic ratings of the high-fat lunch observed following rest. The ratings were significantly higher in restrained individuals, a finding which has been previously reported in a snack study (Green & Blundell, 1996). After exercise, there was a significant increase in the perception of the pleasantness, tastiness and palatability of the foods, independent of the degree of restraint. However, this effect was restricted to the high-fat (low-carbohydrate) foods in unrestrained subjects and to high-carbohydrate (low-fat) foods in restrained eaters. This increase in the perceived pleasantness of the food after exercise was not observed in a similar study conducted in unrestrained males (King & Blundell, 1995). However, previous work suggest that taste preferences vary as a function of dietary restraint and exercise (Kanarek *et al.* 1995).

If restrained eaters use exercise to control eating behaviour, it is possible they differ from unrestrained eaters in physiological characteristics and are physiologically fitter (higher V_{O_2max}). In our sample, dietary restrained subjects had a higher maximal O_2 consumption than unrestrained subjects. Kanarek *et al.* (1995) found a positive relationship between dietary restraint and exercise, in terms of frequency. This finding has not been reported in two other studies (Klesges *et al.* 1992; Tepper *et al.* 1996). As excessive levels of physical activity may play a role in the development of eating disorders, the link between dietary restraint and the use of exercise as a means of controlling weight needs further work. In particular, young athletes who may be at risk of dietary restriction should be monitored (Ziegler *et al.* 1998).

In conclusion, this present study, comparing the short-term effects of exercise and diet manipulations on energy intake in restrained and unrestrained females, showed some similarities and marked differences. In both restrained and unrestrained eaters, there is no energy compensation in response to an acute bout of exercise during the following meal. We hypothesise that in dietary restrained women who are regularly exercising, the combination of physical activity and a low-fat diet could be used advantageously to control appetite, prevent overconsumption and protect against the development of obesity. However, more research should focus on the examination of the psychological factors in the energy intake response to exercise, especially in the long-term.

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